Final Report for DARPA Grant #HR0011-09-1-0027
Covering April 22, 2009 through June 30, 2010

Title: *CSSG: Interactive Realism in Graphics with Complex Materials*
Principle Investigator: *Professor Chris Wyman, The University of Iowa*

Funding for Computer Science Study Group participants had two main priorities: PI attendance at study panel meetings to meet potential collaborators and learn about Department of Defense needs as well as funding for synergistic basic research. My proposal sought to develop novel techniques for interactively simulating lighting from complex sources, reflections from complex material types, and the behavior of participating media under these illumination environments.

I attended all four Computer Science Study Panel meetings, including the welcome and orientation meeting in April 2009, the east coast trip in June 2009, the west coast trip in July 2009, and the intelligence overview in October 2009. These meetings were exceptionally informative, introducing myself and other participants to commonly used jargon and acronyms and investigating challenging computer science problems affecting all branches of the armed forces, defense contractors, most combatant commands, and uniformed personnel ranging from Private to senior Generals.

Particularly useful, for me, was learning in which parts of the Department of Defense the graphics and visualization problems involved significant research challenges, where simple engineering solutions were needed, and where existing solutions are essentially sufficient. Additionally, I learned where significant defense and intelligence problems in related areas, such as computer vision, remain. Perhaps most importantly, I saw that my expertise in fast illumination algorithms applies to many other non-graphics defense problems, ranging from identifying good placement of wireless and radio transmitters to ballistics. Essentially, computer graphics is a type of physics simulation and approximation

In fact, while exploring ballistics problems I made my best connection during the panel. I have had numerous discussions with Lee Butler, a researcher at the Army Research Lab at Aberdeen Proving Ground, visiting him twice (September 2009 and September 2010) and discussing my work at a number of conferences. This collaboration has led to small follow-on projects stemming from this grant's supported research, including an ARO Short Term Innovative Research grant (#W911NF-10-1-0338) and a ARL subcontract, though I expect this collaboration to continue, and grow, in the future. The Top Secret clearance I obtained through the study panel has been exceptionally useful for this collaboration, allowing Lee and I to discuss specific applications of my work that will help guide my future research directions.

Developing new illumination and visibility approximations useful in the context of ballistics were the topic of my CSSG Phase II proposal. While this proposal was ultimately not chosen for funding, some of these research directions were incorporated into my STIR proposal and will likely be explored in future collaborations.

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6. AUTHOR(S)

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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This grant funded PI travel and attendance to Phase I meetings of the 2009 Computer Science Study Panel, development of contacts and collaborations with Department of Defense researchers and agencies, preparation of a Phase II proposal, and synergistic basic research. Specific results include the PI's attendance at four panel meetings, additional meetings with DoD researchers on three other occasions, the preparation of one DoD contract and two DoD proposals (including a Phase II CSSG proposal), and the partial support of four students on synergistic research projects. This research resulted in three papers and three posters in top computer graphics conferences and journals.

15. SUBJECT TERMS

Computer Science Study Group; Computer Graphics; Rendering; Global Illumination; Participating Media

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Chris Wyman
U	U	U		4	19b. TELEPHONE NUMBER *(Include area code)* 319-353-2549

The synergistic research contained in my Phase I proposal included developing novel algorithms for two areas of lighting: efficient multiresolution rendering techniques using frequency based refinement of lighting, targeting global illumination computations, and fast approaches for computing illumination arising from scattering in participating media. For the first problem, our approach was remarkably successful (see list of publications on following page), giving efficient algorithms for rendering global illumination and lighting from complex, dynamic illumination sources. This lighting ranged from the perfect specular reflections depicted in our proposal to diffuse surfaces (in our EGSR 2009 paper) to surfaces with varying reflectance functions (in our EGSR 2010 paper). In fact, this multiresolution rendering approach was the topic of Greg Nichols, my PhD student's, dissertation entitled "Multiresolution Image-Space Rendering for Interactive Global Illumination," which he defended in May 2010. The key insight from this work is that most lighting has structure; this structure can be leveraged to develop heuristics for improving computational efficiencies in a hierarchical way. Prior work has leveraged such structure in object or world space, but focusing on structure evident in screen space gives similar results while involving less computation due to the dimensionality reduction from 3D to 2D.

On the second problem, efficient algorithms for complex illumination in participating media, we made less progress. In fact, our work in this area led to a single paper, currently under submission. However, this work looks extremely promising, allowing certain types of volumetric visibility computations in less than 3 milliseconds per frame (hundreds of frames per second) even for complex geometry with hundreds of thousands of geometrical primitives. In fact, continuing this work is one of the key goals of my STIR grant, as ballistics becomes a volumetric visibility problem after the first collision. The basic insight in this, as yet unpublished, research is that volumetric visibility queries are typically quite coherent; yet standard data structures (like Cartesian grids or kD-trees) do not benefit from this coherence because the particular order of memory accesses introduces incoherence. We develop a new "epipolar" space that allows visibility samples to be accessed in a coherent manner that significantly improves performance. I see numerous potential follow-on directions with useful defense applications, including the generalization to more complex visibility queries.

The expenditure of funds (see itemized list on following pages) basically followed the proposed budget, with the following exceptions. My student, Greg Nichols, had an internship that ran into October, reducing the expenditure on academic year graduate stipends. This savings was used to partially fund two undergraduates this summer (May and June 2010) to work on development on the Army Research Lab's "Virtual Shot Line" program, adding GPU acceleration and exploring how our research algorithms could be incorporated into this framework. Additionally, as a final year PhD student Greg took fewer than 12 credit hours each semester, resulting in a significant savings in the tuition line item. This savings was used for additional travel, plus some computer repairs and purchases.

This grant supported the following journal publications during the reporting period (April 22, 2009 to June 30, 2010):

Greg Nichols, Jeremy Shopf, and Chris Wyman, "Hierarchical Image-Space Radiosity for Interactive Global Illumination." *Computer Graphics Forum 28(4)*, 1141-1149. June 2009. (Special Issue on the 2009 Eurographics Symposium on Rendering)

Greg Nichols, Rajeev Penmatsa, and Chris Wyman, "Interactive, Multiresolution Image-Space Rendering for Dynamic Area Lighting." *Computer Graphics Forum 29(4)*, 1279-1288. June 2010. (Special Issue on the 2010 Eurographics Symposium on Rendering)

Greg Nichols and Chris Wyman, "Interactive Indirect Illumination Using Adaptive Multiresolution Splatting." *IEEE Transactions on Visualization and Computer Graphics 16(5)*, 729-741. September/October 2010.

This grant supported the publication of the following peer-reviewed book chapter during the reporting period:

Chris Wyman, Greg Nichols, and Jeremy Shopf. "Fast, Stencil-Based Multiresolution Rendering for Indirect Illumination." *GPU Pro: Advanced Rendering Techniques*, Chapter 4.1, pages 199-214. Edited by Wolfgang Engel. AK Peters, 2010.

This grant supported the following peer-reviewed conference abstracts:

Greg Nichols and Chris Wyman. "Direct Illumination from Area Lights," presented as a poster at the 2009 *ACM SIGGRAPH*. New Orleans, LA, August 2009.

Greg Nichols, Rajeev Penmatsa, and Chris Wyman. "Direct Illumination from Dynamic Area Lights with Visibility," presented as a poster at the 2010 *ACM Symposium on Interactive 3D Graphics and Games.* Washington D.C., February 2010.

Rajeev Penmatsa, Greg Nichols, and Chris Wyman. "Voxel-Space Ambient Occlusion," presented as a poster at the 2010 *ACM Symposium on Interactive 3D Graphics and Games.* Washington D.C., February 2010.

The grant supported the following work currently under review:

Chris Wyman. "Interactive Voxelized Epipolar Shadow Volumes." Submitted to the 2010 ACM SIGGRAPH Asia Sketches Program.

This grant supported the following presentations:

"Hierarchical Image-Space Radiosity for Interactive Global Illumination," paper presentation at the Eurographics Symposium on Rendering. Girona, Spain. June 2009.

"Direct Illumination from Area Lights," poster presentation at ACM SIGGRAPH. New Orleans, LA. August 2009.

"Direct Illumination from Dynamic Area Lights with Visibility," poster presentation at the ACM Symposium on Interactive 3D Graphics and Games. Washington D.C.. February 2010.

"Voxel-Space Ambient Occlusion," poster presentation at the ACM Symposium on Interactive 3D Graphics and Games, Washington D.C. February 2010.

"Interactive Indirect Illumination Using Adaptive Multiresolution Splatting," paper presentation at the Eurographics Symposium on Rendering. Saarbrucken, Germany. June 2010.

Incurred expenses for the period April 22, 2009 to June 30, 2010 include:

$39,153,62	Salaries for PI, PhD students, and undergraduates
$9,239.38	University fringe benefits
$581.00	PhD tuition waiver costs
$11,256.13	Domestic travel costs
$3,647.66	International travel costs
$3,203.21	Materials and supplies
$165.00	Publication costs
$30,035.00	Indirect costs (Facilities and Administration overhead)
$97,281.00	**Total cost**

Salary costs included:

$20,778.00	For Prof. Chris Wyman as summer salary (6/09-7/09)
$13,415.62	For Greg Nichols as a graduate research assistant (10/09-5/10)
$3,300.00	For Ethan Kerzner as an undergraduate researcher (05/10-06/10)
$1,660.00	For Maranda Franke as an undergraduate researcher (05/10-06/10)

Fringe benefit costs included:

$6,191.83	For Prof. Chris Wyman
$2,616.03	For Greg Nichols
$287.10	For Ethan Kerzner
$144.42	For Maranda Franke

Tuition waiver costs included:

$581.00	For Greg Nichol's post-PhD proposal tuition costs

Domestic travel costs included:

$1,361.48	Prof. Wyman, travel to CSSP Session 1 in Washington, DC
$1,268.96	Prof. Wyman, travel to CSSP Session 2 on the East Coast
$926.23	Prof. Wyman, travel to CSSP Session 3 on the West Coast
$1,749.42	Prof. Wyman, travel to CSSP Session 4 in Washington, DC
$2,501.00	Prof. Wyman & Greg Nichols travel to ACM SIGGRAPH, New Orleans
$906.22	Prof. Wyman, travel to Aberdeen Proving Ground (09/2009)
$2,022.02	Prof. Wyman, Greg Nichols, Rajeev Penmatsa travel to ACM Symposium on Interactive 3D Graphics, Washington DC
$520.80	Prof. Wyman airfare to ACM SIGGRAPH 2010 in Los Angeles, CA

International travel costs included:

$189.76	Greg Nichols, partial registration for EGSR 2009 in Girona, Spain
$1,583.50	Greg Nichols, partial travel to EGSR 2010 in Saarbrucken, Germany
$1,874.40	Prof. Wyman, partial travel to EGSR 2010 in Saarbrucken, Germany

Materials and supply costs included:

$10.00	Department computational fee for maintaining research SVN repository
$161.99	Replacement printer drum for lab laser printer
$360.86	Network disk to allow easy sharing of large research data
$2670.36	Two student research computers

Publication costs included:

$165.00	Printing 1 poster for ACM SIGGRAPH 2009 and 2 for ACM Symposium on Interactive 3D Graphics 2010